Pergamon

Technology In Society, Vol. 19, No. 2, pp. 145–160, 1997

0160-791X/97 $17.00+0.00

PII: S0160-791X(96)00061-9

Alternative Cars: The Contrasting Stories of Steam and Diesel Automotive Engines

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ABSTRACT. This paper discusses why some technologies become so entrenched in our society that it becomes virtually impossible to alter them, and why some challengers nevertheless succeed. It compares two alternatives to the automobile gasoline engine: steam and diesel. The central thesis is that established technologies remain because they have gained symbolic power, are carried by deeply embedded organizational structures, and have fostered strong behavioral patterns. The diesel engine managed to rid itself of the negative symbolism that had for a long time put it at a disadvantage compared to the gasoline engine. It was taken up by the same actors and organizations that supported the gasoline engine, and its engineers saw to it that users did not have to change their patterns of behavior. The steam engine, by contrast, did not succeed in any of these respects: it came to be associated (negatively) with high fuel consumption, its organizational affiliations were weak, and users were never given the opportunity to test their willingness to modify their behavior. © 1997 Elsevier Science Ltd

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Introduction

With few exceptions, the history of technology continues to be written primarily as a series of success stories. It is, after all, the victors who have been the main chroniclers of the past and, in this regard, historians of technology have largely followed suit, writing relatively little about the failed attempts to develop technical artifacts and technological systems.[1] The little that has been written has generally tended to explain failures in technical terms, that is, as failing to provide technical advances over the successful techniques. Failure is rationalized away as an inevitable part of the evolution of technology which, in Darwinian fashion, has generally been seen as a rather ruthless survival of the fittest.[2] The history of automotive technology is no exception to this rule. James Flink, for instance, explains the victory of the automotive gasoline engine over steam and electricity primarily in terms of its better performance in races from the turn of the century onward.[3]

In line with this belief in natural selection (if not necessarily in progress), historians of technology have tended to disregard periodically proposed alternatives to dominant techniques. Even though Lewis Mumford, a pioneer in the history of technology, was greatly interested in technical and societal alternatives, his "alternative" writings aroused much less interest than his historical works.[4] Alternative technology has come to be conceived of primarily as visionary and utopian, the province of science fiction writers and naive romantics rather than historians.[5]

In the 1970s, however, alternative technology was regarded as more than a vision; it existed, albeit outside the academy as a social movement, an explicit form of "cognitive praxis" through which significant numbers of people constructed a new kind of collective identity.[6] There was both the articulation of new world views (a cosmological dimension), new scientific-technical practices (a technological dimension), and the creation of new contexts for knowledge production and dissemination (an organizational dimension).

In both Europe and the United States, the alternative technology movement involved a range of experiments in renewable energy, "ecological" construction and agriculture, and even in alternative design and production processes. There were also training courses, workshops, exhibitions and even organizations established to give the movement a somewhat more coherent form. As Carroll Pursell recently argued, the alternative technology movement only existed a short time, but during that time it opened up the development of technology to new participants. It also helped make it possible to imagine alternative technological futures, to conceive of alternatives to dominant techno-economic structures and systems.[7]

As with many, if not all, social movements, the alternative technology movement was a temporary phenomenon, lasting as an organized movement in most European countries only for a few years. In the United States, as well, the institutions of the appropriate technology movement, had "by the

mid-1980s,...either disappeared or lost their momentum."[8] The experimental and innovative space that had been carved out was rather quickly invaded and eventually colonized by more powerful social actors. In the ensuing years, the cognitive praxis of the movement, through processes of professionalization and incorporation, was broken up and transformed into a number of commercially successful techniques — wind power plants, solar energy, bio-gas, recycling, composting — as well as a range of environmental management and accounting activities conducted within private firms and state agencies. But, as Pursell puts it, there is no longer "an ideological context which can give them political meaning."[9]

Our purpose here is not to bemoan the demise of the alternative technology movement. Rather, we would like to take its rise and fall as a point of departure for taking a new look at some of those who have emerged in the history of automotive technology as they promoted alternatives to the gasoline engine. In order to appreciate their significance, it is not enough to assess their success or failure in merely technical terms; rather, the efforts to create unconventional technologies must be evaluated as a broader social process of cognitive praxis. For just as the alternative technology movement in the 1970s was far more than merely a technical activity, the efforts to develop steam and diesel automotive engines represent something more than mere technical alternatives. Alternative technological developments are best seen, we suggest, as multi-faceted social processes, containing different levels, or dimensions, of cognitive praxis.

Here we compare the commercial failure of the steam engine as an automotive power source with the success of the diesel engine. By looking at these alternative cars as social processes, we suggest that steam cars have been something more than a total failure and diesel engines something less than a complete success. By analyzing the stories of the steam and diesel automotive engines in a symmetrical manner, we want to indicate that success and failure are relative categories in the history of technology, as they probably are in life. Our analysis is based on a model that is derived from our studies of the cognitive praxis of social groups. The general aim is to break down the "defining power" of stabilized technologies into three kinds of reinforcing structures: symbolic, organizational, and behavioral, roughly corresponding to the three dimensions of cognitive praxis mentioned above.[10]

- *Symbolic* structures refer to the values that are associated with technologies — the visions, expectations, and desires — at both the individual and collective level. Lewis Mumford once wrote that as humans our relation to the machine is primarily on a symbolic, psychological plane and, in recent years, there has been some attention given to the "frames of meaning" which inform social life, including technological development. Alternative technologies often succeed or fail largely on the basis of the symbols or visions which are associated with them.[11]
- *Organizational* structures refer to the social systems that support the

dominant technologies and from where attacks on alternatives are often launched. The development of technology takes place not just in formal institutions; in many cases the informal links between individuals, institutions, and artifacts are equally important. The organizational dimension of cognitive praxis is similar. It is often the looser clusters of networks across established institutional contexts which are crucial for the success of new technologies; success is often based on a promoter's ability to break through established institutional frameworks and devise social innovations for technical development.

- By *behavioral* structures, we mean the habits and routines that are found in everyday life, the personal expectations that users have of their technical artifacts, the patterns of domestication that must be dealt with by any successful innovation. To be sure, technologies can serve to reconstruct everyday life in many important ways, but they are usually not given much of a chance if they do not adapt themselves to standard routines of behavior.[12]

An alternative technology seldom succeeds if it poses an alternative at all three levels. Indeed, our contention is that a too-ambitious alternative is less likely to succeed than a conservative one. Perhaps this is the problem with today's electric car: it is associated with many other symbols than the internal combustion engine-driven car, it requires new infrastructures, and it calls for new behavioral patterns all at the same time.[13]

Closing Ranks Around the Gasoline-Driven Automobile

The history of technology is rich in accounts of competing and struggling artifacts and systems. Perhaps most well-known is Thomas Hughes's account of "the battle of the systems" — a phrase which he used to describe the battle between proponents of direct and alternating current in the late 19th century.[14] A short time later, though, we find analyses of the struggle between electric, gasoline, and steam cars at the turn of the century.[15] To contemporary observers these three technologies were options of equal potential — at least until about 1903, when Wilhelm Maybach and Emil Jellinek led the way into what was by then being called "the Mercedes era."[16] The gasoline engine not only came to *symbolize* the engine of the future; it also became, quite literally, a futuristic engine. Even though some of its characteristics (especially in city traffic) were problematic for various user groups, its performance squared with the practice and *behavior* of the economically most powerful group: well-to-do sportsmen who were quite similar to those "young men of means and nerve" that Pinch and Bijker discuss in their analysis of the early history of the bicycle.[17] When, a few years later, Ford Motor Company decided to put gasoline engines in their mass-produced automobiles, this engine also became institutionally secure.

In contrast, both the electric and the steam car were caught in a vicious circle.[18] They came to symbolize femininity and old-fashionedness, respectively — ideals which were not particularly favored in the progress-oriented,

male culture of the day. Furthermore, these cars demanded a behavior that did not square well with user patterns that were developing in the early 1900s, i.e., high speeds, long-distance trips, immediate starting. And last but not least, these automobiles were carried by institutions that both acted in an elitist way and were regarded as archaic — at a time when the mass-produced gasoline-driven automobile began to be the car of the masses.

As a result of interlinked processes at work on all three of the levels just described, automotive engineering began to stabilize around the gasoline engine. Already in 1907, one could read in an American motor journal that "there seems to have come a time when radical changes in construction and design are things of the past."[19] Our contention is that this field of engineering went through a surprisingly quick and widely encompassed process of closure that cannot be explained simply by reference to internally technical factors. Steam and electric cars slowly disappeared from the roads at the same time as steam and electric automotive engines became marginalized in engineering circles. From then on, it became possible to write the early history of automobility as a gasoline success story and a steam and electric failure story.

The First Steam Failure Story

At the turn of the century, it was an open question whether the new internal combustion engine would come to define the automobile. Many early developers of automobiles used steam engines, and well into the 1910s many of the steam-powered automobiles were competitive with gasoline cars.[20] The French engineer, Leon Serpollet, and the American Stanley brothers developed steam cars that performed as well, if not better, than the early gas cars. Serpollet's car, built in the 1890s, made use of several technical improvements: a flash-type generator and advanced metering systems, which solved some of the problems that had plagued steam vehicles in the past. It is worth recalling that there were steam-driven carriages in several countries in the 19th century, but they virtually disappeared from the roads as the result of a few well-publicized explosions, allowing railroads the opportunity to mobilize most of the available transportation investment capital. However, Serpollet's innovations eliminated the possibility of explosions and led to a much quicker head of steam. But, as with steam carriage makers before him, he could not attract the capital necessary. After expressing some interest, Armand Peugeot, like Henry Ford in the United States, chose the internal combustion engine.

F.E. and F.O. Stanley were old-fashioned artisans who built their cars according to technical standards of the past. The Stanley Steamer had a far simpler generator than Serpollet's, and each car was built with loving care. The Stanleys did not believe in advertising nor did they accept the principles of mass production. When Ford visited their plant in 1905, he asked the brothers how many cars they produced in a year. The Stanleys said 650, to which Ford replied, "Why, we make that many in one day in my factory."

Even though the Stanleys built the fastest car on the road for many years, it failed to keep up with the times. The Stanley Steamer needed to have its water refilled fairly frequently since the car lacked a condenser. And the cars were not fashioned for popular taste: they remained long, black and fearful to behold.

The White steamer was, in many respects, a more serious competitor to gasoline-driven cars. But after ten years of production (from 1901 to 1910), the Whites gave up on steam engines and, for that matter, on automobiles and began to specialize in trucks and buses. Even Ford seems to have given some thought to steam. But in the United States, steam cars came to be associated with things "pre-modern" and with an inadequate institutional structure.

Like other small manufacturers who periodically tried to take on the large auto companies, after the 1900s steam car makers were simply unable to mobilize sufficient infrastructural and institutional resources to become serious competitors. Steam cars failed, not for any inherently technical deficiency; rather, we can say their failure was socially constructed.

The First Diesel Success Story

Rudolf Diesel was consumed with the idea of replacing the steam engine. About 1890 when he began to conceptualize the engine that would later bear his name, he was not thinking specifically of automotive applications. His larger vision was to design an engine that could be used wherever steam engines were being used at the time: in ships, railroad locomotives, and for various stationary purposes.[21] In contrast to the steam engine, which had a reputation for scandalously poor efficiency, Diesel claimed that his engine had the potential of reaching the theoretically maximal degree of efficiency. His *Leitbild* was to create an engine that worked in accordance with the theoretically perfect Carnot cycle, as had been imparted to him through Carl von Linde's teaching and Gustav Zeuner's textbooks.[22] Although Diesel's quest was to challenge the steam-engine establishment and create what could somewhat anachronistically be called an alternative technology, he remained within the theoretical boundaries of "technical thermodynamics." Since the foundation relied on by this entire field of engineering originated in the study of the steam engine, Diesel's endeavor was hardly theoretically revolutionary. Instead, the question is whether it turned out to be revolutionary in a practical sense.

Considering that, in hindsight, we know the diesel would indeed replace the steam engine in most areas of application, a traditional, revolutionary success story presents itself immediately. Diesel's engine got a flying start. The 1893 booklet in which he described his ideas about "a rational heat engine" created great public interest.[23] His first speech on the matter triggered an intense debate in engineering circles. Prospective licensees set out on pilgrimages to Augsburg when, four years later, the first commercial prototype was unveiled on the premises of the Maschinenfabrik Augsburg. The road toward victory had begun.

This success story has, however, been challenged at every step — from Diesel's contemporary business enemies to today's scholars. The first obstacle was to find a business partner, but after some hesitation the managing directors at the Maschinenfabrik Augsburg gave the project their mercy. The second was to convince the Augsburg engineers about the viability of Diesel's project. With a background in steam-engine engineering, they were quite skeptical of Diesel's ideas, and they managed to make the new engine more and more similar to the classical steam engine. Although the latter was an external-combustion and the former an internal-combustion engine, large parts of the technical set-up — cylinder, reciprocally moving piston, and crankshaft — were taken from the steam engine. The engine that finally took shape was so different from Diesel's original plans that his patents were subsequently challenged and could not hold up in court. As is so often the case in the history of technology, the new machine did not represent a completely radical, but instead a more gradual shift.

The first breakthrough for the diesel engine was thus not easy or straightforward. The final result was, however, that the diesel replaced the steam engine in most areas of application. The reason was not simply that the diesel was the "better" engine. Rather, it won out because:

1. its proponents successfully exploited the negative symbolism that haunted the steam engine at the end of the 19th century;
2. Rudolf Diesel managed to secure institutional support for his engine from the established machine industry;
3. as the diesel became increasingly similar to the steam engine, users could adopt the novelty without changing their traditional behaviors.

The Second Diesel Success Story

The first success of the diesel engine had its price. Its relatively rapid adoption into areas formerly dominated by the steam engine meant that the diesel gained a reputation for being slow, large, heavy, and inflexible. During the first decades of this century diesels were primarily installed to propel large ships and heavy locomotives, or to drive machines in factories and generators in power plants. None of these cases called for high and variable speeds. With the possible exception of locomotive applications, less weight also was not a primary concern. On the contrary, the diesel found a market, even though it ran slowly and its weight was substantial. The result was not only that the diesel replaced the steam engine in various areas of application, but also that the diesel acquired some of the symbolism associated with steam.

Slowness, largeness, heaviness, and inflexibility are usually negative traits in our culture. In addition, they are not particularly good design characteristics for automotive engines. It has always been clear to automotive designers that trucks, buses, and automobiles have to be equipped with relatively fast, small, light, and flexible engines. Hence, there was general skepticism

when E.H. Tartrais at Peugeot and Prosper l'Orange at Daimler began to experiment with automotive diesel engines in 1908-09. Not much is known about these early attempts. We can only infer that the problems seem to have made diesel manufacture prohibitive for a long time. Only in 1921 did French and German companies present their first prototype diesel cars to the public.

Since the German case has been thoroughly discussed by Knie, let us elaborate the French story somewhat.[24] When Peugeot decided to publish Tartrais' work, it did so with great vigor. Through a spirited PR campaign, word spread about the diesel automobile. Henri Petit, a technical journalist, was given the task of driving the car from Paris to Bordeaux and back again. Afterward, he wrote enthusiastically that the engine "met all the expectations of the Peugeot company." Other commentators were equally intrigued: "By giving its confidence and full assistance to the Tartrais engine, the house of Peugeot deserves the praise of our country. It has indeed oriented itself toward the engine of the future. Well done, engineers!"[25]

The initial euphoria did not last long. The engine emitted so much smoke that fears were expressed that the Paris police might not allow it on the crowded streets of the capital. Peugeot's engineers had a difficult time finding an alloy that could withstand the high temperatures that developed in the cylinder head. Prospective users were not always happy with the rough performance of the car compared to automobiles equipped with gasoline engines. Thus, unable to develop an engine that could attract users other than the technical buffs, in 1926 Peugeot decided to abandon further work on the Tartrais diesel. From then on, the technological initiative in the area of high-speed diesels turned toward Germany and Great Britain.

Removing the heavy air pump that had for so long been an integral part of diesel engineering catalyzed the application of the diesel engine in cars. Rudolf Diesel himself characterized this pump as a necessary evil that made his engine "more complicated and expensive," but he had been unable to suggest another solution.[26] The task of the air pump was to mix air with fuel to ensure optimal combustion — a task that was taken over in the 1920s by various alternative solutions. These alternatives were classified as "mechanical injection," implying that the fuel was forced into the cylinder at high pressure and only there mixed with air. Although it did not gain many direct followers, Tartrais' engine was indeed the first heavy-oil engine that did not employ an air-pump.[27]

With the removal of the air pump — the "crutch" of early diesel engineering — automotive applications became feasible.[28] Diesel engines could now be made lighter and smaller, but the problems of speed and flexibility remained. The challenge was to create a functional relationship between the accelerator pedal and the speeds of the injector pumps and the pistons/crank shafts. Without getting into details, this problem was solved by means of intricate cam shaft systems that ensured that injection took place at exactly the right fraction of a second (just before the piston is at

the top of the cylinder). Although these solutions were difficult to perfect, the primary path to higher speeds now lay open. Indeed, much of the subsequent history of diesel engineering became an attempt to design engines that could be run with ever more revolutions per minute.

This trajectory toward higher speeds was strikingly universal, as was the movement toward more power. Companies in Germany, Great Britain, the United States, Italy, Sweden, France, and elsewhere struggled to develop engines that could be driven with more rpm's and deliver more horsepower without breaking apart. As one historian described the market demands in the mid-1930s: "... cries for more power were heard from the truckers who hauled heavy loads through mountains...."[29] This situation was by no means limited to hilly regions. Users everywhere in the industrialized world clamored for a diesel engine which offered the same functions that they had become acquainted with in the gasoline engine. Through their everyday use of gasoline engines, they were developing a behavior which presupposed an engine with at least 50 hp. (in the U.S. 150 hp.) and a maximum speed of at least 1500 r.p.m. If the diesel expected to make any inroads into the bus and truck market, it had to give users a performance on a par with the gasoline engine. Success presupposed adjustment.

The history of the French company, Société des Automobiles Berliet, illustrates these trends. Founded by Marius Berliet in Lyon at the end of the 19th century, the firm had considerable experience in the construction and manufacture of gasoline engines and heavy vehicles.[30] When Berliet, after some difficult years in the mid-1920s, began to look for new exciting projects, his eyes fell on the diesel. Since gasoline was not always easy to obtain, particularly in the French colonies, the prospect of offering the public an engine that could run on vegetable oils made the diesel an interesting prospect.

It was, however, beyond the scope of the Berliet organization to design and develop its own heavy-oil engine, so the director decided to turn to Germany and Switzerland for help. License rights were secured in 1930, and production could start one year later. The license was issued by the famous Robert Bosch company of Stuttgart, and the engine was equipped with the Swiss ACRO mechanical injection system. Despite initial troubles, Berliet's diesel turned out to be a commercial success: "The [French automobile] industry also moved into the production of diesel trucks when the Berliet Company began to specialize and use them as a basis for an unexpected revival."[31] Between 1931 and 1936, the company sold 7400 ACRO engines.

The Berliet-ACRO diesel seems to have given customers what they wanted. The largest truck engine offered by the company could deliver 125 hp, a favorable comparison with gasoline truck engines already on the French market. The "presumptive anomaly" of the engine was the speed.[32] It was not advisable to exceed 1500 r.p.m. with the ACRO system.[33] In particular, drivers of buses and small trucks were not happy with the relatively poor acceleration that occurred as a result of this low engine speed.

Although most buyers were happy with the lower running costs of "dieselization," the inadequate performance issue strengthened the negative symbolism that was already associated with the diesel: it is a slow and sluggish engine.

To counter this not unfounded prejudice, Berliet began looking for a substitute for the ACRO system. His search took him to Great Britain. After lengthy negotiations with Ricardo and Co. in Old Shoreham, and after one year of local modification work, the first truck equipped with a Berliet-Ricardo engine could be found on the roads of Lyon.[34] With this engine it was not only possible to reach 150 hp, but also as much as 2200 r.p.m. Customers were delighted, and 8000 Ricardo engines were sold before World War II abruptly forced all French automobile manufacturers to stop their diesel lines. After the war, the trajectories toward higher speeds and more power continued; in 1959 when Berliet substituted a German MAN design for the Ricardo engine, the largest engine was able to deliver 180 hp and 2500 r.p.m.

As hinted at above, these developments were not limited to France, and the diesel was well on its way to becoming a serious alternative to the gasoline engine. The first inroads into buses and light trucks occurred in the 1930s, and during the same time it was also taken up by the military in several countries, albeit not in France. After the war, the diesel found a niche in the heavy-truck market. Due to relatively high fuel prices in Europe and more concerted efforts from the large producers, commercial success was stronger here than in the United States. Ford never picked up the diesel, and General Motors put most of its efforts into the railway diesel.

To summarize, the automotive diesel became a viable alternative to the gasoline engine only after:

1. the diesel was no longer strongly associated with negative symbols of heaviness, slowness, and sluggishness;
2. it was institutionally secured both among automobile producers and the oil industry; and
3. it did not force users to change the behavior they had become accustomed to after decades with gasoline-powered vehicles.

The Second Steam Failure Story

In the late 1960s, significant efforts were made throughout the industrialized world to develop alternative automotive engines. Small engineering firms, backyard inventors, as well as engineers at the French electricity company studied by Michel Callon, promoted various alternative engines which, in the early 1970s, were tested and developed in both Europe and the United States.[35] Some of the most substantial efforts in the United States were devoted to steam-powered automobiles. In particular, the entrance of the inventor-entrepreneur, William Lear, into the steam car business in 1968 created interest both within and outside the automotive industry.[36] Lear

invested millions of dollars in developing a practicable and commercially viable steam automobile, and there were a number of other companies that were established to take part in various demonstration projects that were set up in the aftermath of the Clean Air Act of 1970.

These efforts were inspired by the emergence of the environmental movement, which singled out automotive air pollution as one of the main components of the growing environmental crisis. As early as 1958, Lewis Mumford had written in *The Highway and the City* about the dangers of automotive air pollution, and several books and magazine articles in the 1960s identified the gasoline automobile as the main contributor to air pollution. At the same time, in California, the Air Resources Board conducted scientific investigations of atmospheric smog and thereafter proposed regulations that would limit exhaust emissions from automobiles. In the mid-1960s, a number of investigative commissions were established, and in 1968, the Senate held hearings on alternatives to the internal combustion engine, with testimony heard from the promoters of alternative engines as well as representatives from the automotive companies.

By 1970, the steam car had come to be seen by many as an alternative that was worth taking seriously. The steam car carried with it a number of symbolic meanings. On the one hand, it offered pollution-free driving, the possibility of being able to drive a clean automobile. It is worth recalling that in the 1960s environmentalism was generally not opposed to technology. The perspective presented in books such as Rachel Carson's *Silent Spring* and Ralph Nader's *Unsafe at Any Speed* was not anti-technological; rather, it was that technology needed to be redirected based on environmental and public safety interests.[37] Steam cars could lead us down "the road not taken."

On the other hand, the steam car also could appeal to a certain segment of the population who collected old cars, especially those who remembered the elegant, well-built Stanley Steamers of the turn of the century. There was a certain appeal to tradition, to an older "age of artisans," that came to be associated with steam cars. Articles in the popular press combined these symbolic meanings; when William Lear came along, he was often portrayed as the individual inventor who would take on Detroit, appealing to a cultural image of the artisan opposed to big business.[38]

Institutionally, the steam alternative was based on loose networks of small firms linked through state agencies in California and Washington. These institutional linkages proved difficult to formalize or solidify; and, from the outset, the large automotive companies worked actively to de-link the steam car makers through various kinds of alternative support. Thermo Electron, one of the more promising companies on the East Coast, received a contract from Ford Motor Company to develop a steam motor for boats; similarly, Lear was given bodies for his test vehicles from General Motors but never any financial support, although he actively sought more substantial connections.

Federal and state officials were unable to serve as "brokers" among the

steam companies, nor was any one of the steam car makers able to take on the role of leading entrepreneur, even though Lear certainly tried. In the United States, it proved difficult to develop alternative institutions to the motor companies, and when the environmental organizations grew more radical in the early 1970s, there was no organized support from that quarter either.[39] A 1974 report submitted to the National Science Foundation called for a substantially increased federal government role in alternative automotive powerplants, but there was no proposal for "social innovations." Any expanded R&D had to be conducted within the automotive industry:

For applied research and exploratory engine development, there are a variety of competent research institutions; with additional funds the capacity in these areas could be increased. But when the work comes closer to the manufacturing process, then tradeoffs with other aspects of overall systems design, the integration of the engine into the vehicle, extensive field testing, suitability of the design for mass production and marketing questions become important, and the expertise is more and more the province of the automobile industry. This means that the latter stages of R&D can only be done in a cost-effective way by the major automobile manufacturers themselves, or by other industries with similar close contact with this or a similar marketplace.[40]

The major automobile manufacturers, however, were simply not interested. As Henry Ford II put it at the time, "We have tremendous investments in facilities for engines, transmissions and axles, and I can't see throwing these away just because the electric car doesn't emit fumes."[41] Instead, the industry response to the Clean Air Act of 1970 was the introduction of the catalytic muffler which, by 1975, had been adopted by all the major manufacturers.[42]

The final death blow to the steam car's return to the commercial marketplace was dealt by the oil crisis of 1973-74. For while the steam cars that were tested both in California and by the federal Environmental Protection Agency met or even surpassed the emission requirements of the Clean Air Act, they were, as could be expected, inefficient users of fuel. Indeed, their fuel efficiency was identified as one of the main deficiencies in all the evaluation reports.

In the final report of the California Clean Car Project, it was stated that, "While our primary goal of low emissions was largely achieved, much engineering development work remains if the steam car is to achieve a competitive base. Our experimental cars consumed about twice as much fuel as an ICE car of the same weight class."[43] Here, however, the conclusion was positive, almost upbeat:

Given sufficient and continuous technical development the steam-powered automobile should be able to reach competitive levels of fuel economy. Additionally, the multi-fuel capability of the steam engine to burn a number of different fuels is attractive in the light of diminishing oil reserves.[44]

By 1975, however, the tone of the evaluative discourse had grown increasingly pessimistic. A report from the Jet Propulsion Laboratory at the California Institute of Technology, based on an ambitious 18-month study performed under a grant from the Ford Motor Company, depicted the fuel inefficiency of the steam car as a "fundamental thermodynamic limitation."[45] Even though a later report, commissioned by the U.S. Energy Research and Development Administration, argued that fuel consumption by steam cars could be reduced significantly with "development of the components and the system," the JPL/Ford report was the one that apparently had the most widespread dissemination in automotive circles.[46] Even in Sweden, where Saab had supported a small research effort on steam cars, the JPL report was later identified by the research team's leader as the main factor in slowing down and eventually stopping the experimental program.[47]

In reviewing the situation in 1986, Charles Amann of the engine research department at General Motors, concluded that it had been fuel efficiency that killed off the steam car's return in the 1970s:

> During the decade beginning in the late 1960s, no less than eight different steam-engine powered cars were sponsored and demonstrated in the US...In all probability the fuel economy and emissions of any of these steam cars could have been improved with additional effort, but the fuel-economy shortfall was sufficient to discourage continuation. Today the steam car is no longer considered a serious contender.[48]

To summarize:

1. the steam car did not survive the changes in symbolism around the automobile that took place in the broader environmental debate;
2. it was not able to mobilize sufficient institutional support; and
3. its ability to reduce pollution was not sufficient to offset its inability to alter behavior in a new direction, namely to save fuel.[49]

Conclusions

One of the few historians to examine seriously the roads not taken in technological development is David Noble who, in his book, *Forces of Production*, contrasted the failure of record-playback to the successful technology of numerical control in machine tool production. Noble's book was explicitly political; he tried to show that success and failure in the case he described had been, to a large extent, based on the varying degrees of political support given to the different technologies. As he put it, "While new inventions are always at the outset 'alternative technologies,' challenges to established ways of doing things which are initially received with caution and skepticism, some fit within the dominant scheme and others do not." For Noble,

> ... any effort to reconstruct lost alternatives, to travel down roads not taken, serves several purposes at once. First, it fills out the historical record and thus lays to rest

the convenient fictions fostered by the ahistorical ideology of technological progress. Second, it reawakens us to a broader and largely available realm of possibilities. Third, it casts existing technologies in a new and critical light and thus stimulates reflection. Finally, and most important, such study of lost alternatives, which reveals the actual process of technological development, reveals also the patterns of power, cultural values and the dominant ideas of the society which shaped that development.[50]

In technological development, failure is as much a social construction as is success. The different fates suffered by diesel and steam-powered automobiles were not the result of purely technical considerations (if such things ever exist) but of a variety of social, cultural and, of course, technical factors. The diesel engine found a niche for itself in the automotive industry by fulfilling a number of institutional and behavioral requirements without challenging expectations or values associated with automotive performance. In the case of steam cars, the alternative value of pollution-free driving was not strong enough to motivate institutional or behavioral alternatives. In addition, there was an institutional bias against the steam car that became mobilized in both theory and practice: Ford sponsored an influential evaluation that (overly) critically portrayed the potential of steam cars, while General Motors developed a conservative solution to automotive air pollution, namely, the catalytic muffler. Alternative technologies must not merely provide alternative values or expectations. They must, even more crucially, generate sufficiently strong institutional support, and they must not be seen to challenge accepted standards of (socio-technical) behavior. In the end, the diesel engine succeeded by being a conservative alternative, and the steam car failed because it remained too radical.

The diesel slowly but surely rid itself of the symbolism that had for a long time put it at a disadvantage compared to the gasoline engine. It was embraced by the same actors and organizations that had supported the gasoline engine; its engineers managed to provide users with functions that were so familiar that they did not have to change their set patterns of behavior.

The steamer did not succeed in any of these respects. Its meaning came to be associated negatively with fuel consumption; its organizational affiliations were weak; and users were never given the opportunity to test their willingness to modify their behavior.

Our paper can perhaps provide food for thought for all those, from engineers to political activists, who seek to change established technical practices. We need to take more seriously the dead ends, the roads not taken, in the history of technology. History seldom traverses a straight and narrow road down some technically determined superhighway. Rather, we suggest the metaphor of a series of crossroads or intersections, where technical alternatives are selected primarily for non-technical reasons.

Notes

1. A special issue on technological failures has been published, appropriately enough, not in a historical journal, even though all the articles were historical, but in *Social Studies of Science*, 1992, 22.

2. Evolutionary views of technological change are presented in Bassalla, G., ***The Evolution of Technology***, Cambridge, 1988 and, in another disciplinary context, in Nelson, R. and Winter, S., ***An Evolutionary Theory of Economic Change***, Harvard University Press, Cambridge, MA, 1982.
3. Flink, J., ***America Adopts the Automobile, 1895-1910.*** MIT Press, Cambridge, MA, 1970.
4. For a full assessment of Mumford's achievements, see and Hughes A. and T., (eds) ***Lewis Mumford: Public Intellectual***, Oxford University Press, New York, 1990). In addition to the various asides to be found in ***Technics and Civilization***, Mumford devoted several chapters in ***The Story of Utopias***, ***The Culture of Cities***, and ***The Condition of Man*** to alternative technological visions, from regionalism and garden cities to the polytechnical vision of William Morris.
5. Howard Segal, one of the few historians of technology interested in alternatives, has written primarily on technological utopias in literature, rather than in actuality. See: Segal, H., ***Technological Utopianism in American Culture***, University of Chicago Press, Chicago, 1985.
6. Eyerman, R. and Jamison, A., *Social Movements: A Cognitive Approach*, Penn State Press, University Park, PA, 1991.
7. Pursell, C. The rise and fall of the appropriate technology movement in the United States, 1965-1985, ***Technology and Culture***, **34** (1993) 629-637
8. *Ibid.*, p. 629.
9. *Ibid.*
10. For the concept of "defining power," see Hård, M. and Knie, A., The ruler of the game: the defining power of the standard automobile. In ***The Car and Its Environments: The Past, Present and Future of the Motorcar in Europe***, ed. K. H. Sorensen, European Commission, Luxembourg, 1994, pp. 137-158.
11. Carlson, W.B., Artifacts and frames of meaning: Thomas A. Edison, his managers, and the cultural construction of motion pictures. In ***Shaping Technology/Building Society. Studies in Sociotechnical Change***, ed. W. Bijker and J. Law, MIT Press, Cambridge, MA, 1992, pp. 175-198. The symbolism of the machine is, of course, a recurrent theme in ***Technics and Civilization***.
12. Hård, M. Technology as practice: local and global closure processes in diesel-engine design, *Social Studies of Science*, **24** (1994) 549-585
13. For an analysis of Berlin's experiences with the electric car, which supports this argument, see Knie, A. and Berthold, O., Das Ceteris paribus-Syndrom in der Mobilitätspolitik. Tatsächliche Nutzungsprofile von elektrischen Strassenfahrzeugen, unpublished manuscript, WZB, Berlin, 1995.
14. Hughes, T. P., ***Networks of Power: Electrification in Western Society, 1880-1930***, Johns Hopkins University Press, Baltimore, MD, 1983.
15. Flink, *op. cit.*; Volti, R., Why internal combustion?, ***American Heritage of Invention and Technology***, Vol. 6, Fall, 1990.
16. See, for example, Lavergne, G., ***Manuel théoretique et pratique de l'automobile sur route. Vapeur-petrole-électricité***, Ch. Beranger, Paris, 1900. F. Sass, ***Geschichte des deutschen Verbrennungsmotorenbaues von 1860 bis 1918***, Berlin, 1962, p. 79. For a more elaborated analysis of how the gasoline engine won out, see Hård and Knie, *op. cit.*
17. Pinch, T. J. and Bijker, W. E., The social construction of facts and artifacts: or how the sociology of science and the sociology of technology might benefit each other. In ***The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology***, eds W. E. Bijker, T. P. Hughes and T. J. Pinch, MIT Press, Cambridge, MA, 1987.
18. Jamison, A., ***The Steam-Powered Automobile: An Answer to Air Pollution***. Indiana University Press, Bloomington, IN, 1970.
19. Have Innovations Ended?, ***Motor Age***, 16 May, 1907. Quoted in Volti, R., Alternative internal combustion engines, 1900-1915. In ***Automobile Engineering in a Dead End: Mainstream and Alternative Developments in the 20th Century***, ed. M. Hård, Unit for Human Technology, Gothenburg University, 1992, pp. 11-23; here: p. 21.
20. The following paragraphs are based on Jamison, *op. cit.*
21. Bryant, L., The development of the diesel engine. ***Technology and Culture***, 1976, **17**, 432-446; Knie, A., ***Diesel- Karriere einer Technik: Genese und Formierungsprozesse im Motorenbau***, Ed. Sigma, Berlin, 1991; Thomas, D. E. Jr, ***Diesel: Technology and Society in Industrial Germany***, University of Alabama Press, Tuscaloosa, AL, 1987.
22. Dierkes, M. et al., ***Leitbild und Technik. Zur Enstehung und Steuerung technischer Innovationen***, Ed. Sigma, Berlin, 1992; Hård, M., ***Machines are Frozen Spirit: The Scientification of Refrigeration and Brewing Technology in the 19th Century—A Weberian Interpretation***, Campus and Westview, Frankfurt, Germany, 1994.
23. Diesel, R., ***Theorie und Konstruktion eines rationellen Wärmemoters zum Ersatz der Dampfmaschine und der heute bekannten Verbrennungsmotoren***. Springer, Berlin, 1893.
24. Knie, *op. cit.*

25. Quoted from Dumont, P., *Peugeot sous le signe du lion*, Paris, 1976, pp. 386, 379 (our translation).
26. Sass, *op. cit.*, p. 462.
27. Hausfelder, L., *Die kompressorlose Dieselmaschine. Ihre Entwicklung auf Grund der in-und ausländischen Patent-Literatur*, M. Krayn, Berlin, 1928, p. 188.
28. Knie, *op. cit.*, p. 194.
29. Rowell, J. W., The diesel came to Indiana in the horse-and-buggy days. *Indiana Magazine of History*, Vol. 82, 1986, pp. 303-333; here: p. 332.
30. Borgé, J. and Viassnoff, N., *Berliet de Lyon*. Éditions Pratiques Automobiles, Paris, 1981.
31. Bardou, J. et al., *The Automobile Revolution: The Impact of an Industry*. University of North Carolina Press, Chapel Hill, NC, 1982, p. 145.
32. On the concept of "presumptive anomaly," see Constant, E.W., *The Origins of the Turbojet Revolution*. Johns Hopkins University Press, Baltimore, MD, 1980.
33. P. Berliet, "Le fabrication du moteur diesel chez Berliet," manuscript, Fondation de l'Automobile Marius Berliet, Nov. 1994. Paul Berliet is Marius's son and started working in the company in 1935. He now directs the Fondation de l'Automobile Marius Berliet in Lyon.
34. This whole transfer process can be reconstructed from material in the file, "Berliet-Licence Ricardo 1935 Moteur Diesel" at Fondation de l'Automobile Marius Berliet.
35. On the French electric car, see Callon, M., Society in the making: the study of technology as a tool for sociological analysis. In *The Social Construction of Technological Systems*, ed. W. Bijker *et al.* MIT Press, Cambridge, MA, 1987, pp. 83-103.
36. These developments are described in Jamison, *op. cit.*
37. Jamison, A., Debating the Car in the '60s and the '90s: similarities and differences. *Technology in Society*, 1995, No. 4.
38. See Wells, D., Lear's steam dream: a reality? *Motor Trend*, June 1969; Ludvigsen, K., Lear: the steam king? *Motor Trend*, February 1971; Schiller, R., Bill Lear: inventor of the impossible. *Reader's Digest*, August 1971.
39. One example of this "radicalization" of the environmental debate was the symbolic burying of an automobile at the first Earth Day in April, 1970. Another was the critique of technology fixes that came to be expressed in the early 1970s, along with the search for alternative technologies. James Ridgway referred explicitly to the efforts to develop steam cars in *The Politics of Ecology* (Boston, 1970), depicting the various activities to develop steam cars as diversions from the more crucial task of confronting the powerful position of the automobile companies. None of the new environmental organizations that emerged in the early 1970s devoted attention to alternative automotive engines.
40. Heywood, J.B. *et al.*, The role for Federal R&D on alternative automotive power systems. Report to the Office of Energy R&D Policy, National Science Foundation, by Energy Laboratory, MIT, November 1974, p. 53.
41. Ford, H. II, quoted in "An Informal Visit with Henry Ford." *Look*, May 28, 1968. Here: from Jamison 1970, *op. cit.*, p. 30.
42. Maruo, K., The three-way "catalysis" — how the General Motors three-Way catalyst became the ruling technical solution to the automobile emission problem. In *Automobile Engineering in a Dead End*, ed. Hård, M., Gothenburg, 1992.
43. California Clean Car Project Final Report, Assembly Office of Research, Sacramento, 1974, p. 14.
44. *Ibid.*
45. Stephenson, R.R. *et al.*, Should we have a new engine? An automobile power systems evaluation. Jet Propulsion Laboratory, August 1975, p. 56.
46. Luchter, S. and Renner, R., An assessment of the technology of Rankine engines for automobiles. Division of Transportation Energy Conservation. ERDA, Washington, 1977, p. 76. Reitze Jr, A. W., Running out of steam, *Environment*, 1977, **19**, 36-37.
47. Ramberg, M., Hur var det med den omtalade ångbilen?, unpublished manuscript. Linköping University, 1982, p. 17ff.
48. Amann, C.A., How shall we power tomorrow's automobile? In *Automotive Engine Alternatives*, ed. R.L. Evans. Plenum, New York, 1986, pp. 4-5.
49. It is noteworthy that, at about the same time, the Wankel engine, which was, for many, an even more serious contender than the steam engine, encountered similar difficulties, due to its allegedly low fuel-efficiency. As with steam, the Wankel met with institutional resistance, and the oil crisis provided a rationale for automakers not going ahead with the alternative engine. For details, see Andreas Knie, *Wankel—Mut in der Autoindustrie*. Ed Sigma, Berlin, 1994.
50. Noble, D., *Forces of Production*. Knopf, New York, 1984, p. 145.